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RADIUM

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VOL. III JUNE, 1914 No. 3

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A MONTHLY JOURNAL DEVOTED TO THE CHEMISTRY
PHYSICS AND THERAPEUTICS OF RADIUM
AND RADIO-ACTIVE SUBSTANCES

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RADIUM

A MONTHLY JOURNAL DEVOTED TO THE CHEMISTRY, PHYSICS AND THERAPEUTICS OF RADIUM AND RADIO-ACTIVE SUBSTANCES.

Edited and Published by Charles H. Viol, Ph. D. and William H. Cameron, M. D., with the assistance of collaborators working in the fields of Radiochemistry, Radioactivity and Radiumtherapy.

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VOL. III JUNE, 1914 No. 3

GLOSSARY OF TERMS IN RADIOACTIVITY*

BY HERMAN SCHLUNDT, PH.D.

ALPHA RAYS. One of the types of radiation from radioactive substances, consisting of positively charged helium atoms, expelled with a velocity about one-twentieth that of light, and bearing a charge twice that of the hydrogen atom in electrolysis, (or 9.3×10^{-10} electrostatic units) : [0.00000000093]. In their passage through matter the rays cause ionization and thus render air conductive of electricity, and so discharge electroscopes. They also affect a photographic plate, and produce phosphorescence in certain substances, e. g., *Sidot's* blende. The rays are slightly deviated in a strong magnetic field at right angles to their path. The alpha rays from different radioactive substances have different velocities of expulsion and ionize the air for different distances referred to as the "range." The number of ions per cm. of path varies, increasing rapidly to a maximum within a few mm. of the end of the range. One alpha particle from Ra C, initial velocity, 2.06×10^9 (2,060,000,000) cm. per sec., produces 2.37×10^5 (237,000) ions. Its energy is 1.31×10^{-5} ergs. See also range, scattering, absorption, transformation.

ABSORPTION OF ALPHA RAYS. An atomic property of substances, proportional to the square root of the atomic weight, if

*This Glossary was prepared by L. A. Bell, C. E. Betz, J. G. Hawthorne, H. T. Newlon, O. E. Sheppard and John D. Waugh, students in radioactivity, 1912-13, at the University of Missouri, and revised by Professor Herman Schlundt, Chairman of the Department of Chemistry in the University of Missouri. As given here some of the terms of purely physical interest have been omitted, others have been defined more simply and some terms frequently encountered in the literature of radium-therapy have been added. Page references, unless otherwise specified, are to Rutherford's "Radio-active Substances and Their Radiations." C. H. Viol.

elementary, or to the sum of the square roots of the constituent atoms, if a compound or mixture. It does not follow a simple exponential law, the exact law being unknown. All alpha rays are easily absorbed, 3 to 8 cm. of air (depending on the range) or 0.01 to 0.03 mm. thickness of aluminum being sufficient to completely absorb them.

ABSORPTION OF RAYS : ABSORPTION COEFFICIENT. Beta rays when homogeneous are absorbed according to the following simple exponential law: $I_t/I_0 = e^{-ut}$; I_0 and I_t are the intensities of the rays initially and after passage through a thickness of matter t, u being the coefficient of absorption and e a constant, the base of the natural logarithms, having a value 2.71828. If t^1 is the thickness of the absorbing layer in centimeters that reduces the intensity to half value, $t^1 = 0.693/u$. For beta rays from radium the value of u for aluminum is 200 cm., so that t^1 is $0.693/200 = 0.00346$ cm. of aluminum to reduce the intensity of the rays one half. Gamma rays follow the same exponential law, the average value of u for the gamma rays of radium being 0.50. From this $t^1 = 0.693/0.5 = 1.38$ cm. of lead to absorb half of these rays.

ACTINIUM, AND ACTINIUM SERIES. Actinium is a radio-element associated with uranium in pitchblende. It is the parent of a series of disintegration products,—the actinium series,—supposedly a branch product of the uranium series. Actinium itself is rayless and little is known concerning it. The members of the actinium series all have short life periods. The actinium series embraces eight members as shown in the following tabulated data:

TABLE 1—Actinium Series

Name	Half Period P	Av. Life L	Radioactive Constant	Rays
Actinium	?	?	?	Rayless.
Radio Act.	19.5 days	28.1 days	0.0355 day	alpha and beta
Act. X.	10.2 days	14.7 days	0.068 day	alpha
Emanation	3.9 sec.	5.6 sec.	0.178 sec.	alpha
Act. A.	0.002 sec.	0.0029 sec.	350 sec.	alpha
Act. B.	36 min.	52 min.	0.0193 min	alpha
Act. C.	2.1 min.	.30 min.	0.33 min.	soft beta
Act. D.	4.71 min.	6.8 min.	0.147 min.	beta and gamma

ACTIVE DEPOSIT. Name given to the non-volatile disintegration products of the emanations. Active deposits of *rapid* change consist of the A products and its successors which are relatively short-lived. RaA,RaB,RaC_1 and RaC_2 of the radium series constitute the active deposit of rapid change, while the members following, (see radium series) make up the active deposit of slow decay. The active deposit is conveniently collected upon a negatively charged plate exposed to the emanation. Other names for active deposit are "excited activity" and "induced activity."

ACTIVITY. Most of the older radium preparations were sold on the basis of an "activity" expressed in terms of the alpha ray activity of uranium metal as unity. This gave large numbers since pure radium bromide was set as 2,000,000 times as active as uranium metal. Half pure radium bromide was said to be of 1,000,000 activity. Unfortunately when such preparations are now

compared with radium standards, comparisons being made by means of the gamma rays, it is found in most cases that the radium element content is far below that which is expected. The standardization of all radium preparations on the basis of the International Radium Standard is now the accepted practice, and all preparations should be purchased *only on the guarantee by responsible dealers of the content of radioactive element in terms of this standard* or with certificates from the Bureau of Standards. The description of preparations in terms of their radium element content is the best practice since the therapeutic value is dependent on the radium element content.

AGE OF RADIO-ELEMENTS. The smallest estimate of the age of primary thorium and uranium minerals is 200 million years.

AIR LEAK. Rate of discharge of the leaf of an electroscope, or rate of movement of the needle of electrometers of the Dolezalek type, due to the ions normally present in the air, assuming the insulation of the instruments to be perfect. On land 1 c. c. of air, under standard conditions of temperature and pressure, normally contains about 1000 to 2000 ions, and about 5 to 6 ions are probably produced per sec., the number depending upon the locality, the walls of the instruments, and weather conditions.

ANALYSIS OF RADIOACTIVE PRODUCTS FROM IONIZATION CURVES. The composition and sequence of products in a mixture, e. g., the active deposits of rapid change, and the radioactive constants of the components may be determined from various sets of ionization curves representing respectively the decay of the alpha, beta, and gamma rays for different periods of exposure. Cf. R., 435, 449, 487, 523, 535, et. seq. See Ionization Curves.

APPLICATORS. See Varnish Applicators.

AVERAGE LIFE. See Life.

BETA RAYS. A type of radiation from some radioactive substances more penetrating than the alpha and identical with the negatively charged particles constituting the cathose rays. Beta rays are more readily deflected by a magnetic field than alpha rays. They are projected with a velocity of the same order as that of light. The exact value of the charge borne by the beta particle has not as yet been determined satisfactorily on account of the interfering secondary rays that arise when beta rays traverse matter. It is assumed that each beta particle carries the elemental charge, 4.65×10^{-10} electrostatic units. Gamma rays never appear independently of beta rays. Beta rays impinging upon matter give rise to gamma rays called "excited" gamma rays.

BECQUEREL RAYS. Name given to the radiations from uranium and uranium compounds at the time of their first discovery by *Becquerel.*

BISMUTH. The most probable end product of the thorium series. Not a radioactive element but closely allied to polonium, the two separating together from solutions of uranium minerals. Polonium may be separated from solutions by immersing a rod of Bi or rotating a disc of Bi in the solution. A bismuth rod coated with polonium is known as "radioactive bismuth."

BRONSON RESISTANCE. A convenient device for measuring ionization currents with a quadrant electrometer by the method of steady deflections. It is a constant air resistance in the form of an ionization chamber, the conductivity of the air between the electrodes being maintained by a trace of radium salt on a small plate.

CANAL RAYS. *Goldstein* first observed radiations from a perforated cathodes in a vacuum tube opposite in direction to the cathode rays, i. e., behind the perforated cathode. The rays consist of positively charged particles of the same order of mass as the hydrogen atom. They produce phosphorescence and are deflected in a magnetic field.

CARNOTITE. A uranium vanadium bearing mineral whose ores constitute an important source of radium.

CAPACITY. The electrostatic capacity of an electrometer or other measuring system of small currents is the quantity of electricity required to charge it to unit potential. The current in an electroscope when the capacity is known can be calculated by the equation $I = V/t$; where I is the current, (electrostatic units) C, the capacity of the electroscope, V, the potential difference (electrostatic units) as measured by the fall of the leaf in the time, t, (V equals volts/300).

CATHODE RAYS. Negatively charged particles projected from the cathode in a vacuum tube at low pressure and similar to beta rays from radioactive substances.

UNIT CHARGE. The elementary unit of electricity,—the charge carried by the hydrogen ion in electrolysis. Its value is 4.65×10^{-10} electrostatic units. Alpha particles carry two such positive charges and the beta particle one such negative charge.

COLORATION OF BODIES BY RADIUM RAYS. Glass tubes in which radium salts are kept soon assume a beautiful violet color. The chemical change produced is attributed to the beta rays. On heating a colored tube a strong luminosity is observed and the coloration largely disappears.

CONDUCTIVITY OF GASES. The presence of ions,—carriers of positive and negative charges,—in a gas renders it a conductor of the electric current. The alpha particles from radioactive substances are particularly effective in producing ionization in the surrounding air. The ionizing particle in passing through a gas molecule removes one or more negative corpuscles, electrons, each of which at ordinary pressures and temperatures acts as a nucleus around which a cluster of neutral molecules gathers and thus becomes the negative ion. After the removal of an electron the molecule retains a positive charge; and so becomes the center of a cluster of neutral molecules constituting the positive ion. Perhaps the process of ionization is more complex:—the initial step may consist in the removal of a neutral doublet, which yields a positive and negative charge, each of which becomes attached, under ordinary conditions, to the molecules of the gas. In an electrostatic field the gas ions move in opposite directions and this migration constitutes the electric current or ionization current in the gas.

RADIOACTIVE CONSTANT. The radioactive constant usually designated by λ, is the fraction of the total amount of radioactive substance disintegrating in the unit of time, according to the simple exponential law of radioactive change: $N/No = e^{-\lambda t}$ For example consider 1000 atoms of radium emanation, the radioactive constant for radium emanation is 0.0075, when t is expressed in hours. Thus at the end of one hour 0.0075 or 3/4% of the emanation atoms have disintegrated. In the next hour the same proportion 0.0075 of the remaining emanation atoms disintegrates, and so on. Thus after the first hour there will be left only 99¼% of the emanation atoms or 992 atoms. After the second hour there will be left 99¼% of the (992) atoms which were present at the beginning of the second hour. This number is 985. The calculation by this method is too tedious and to facilitate calculations the formula, given above, is used. Tabulated data on the decay of radium emanation and its accumulation in a sealed radium preparation initially free from emanation are given under radium emanation, q. v. See also under Transformation.

COSMICAL RADIOACTIVITY. Radioactive phenomena of bodies other than the earth:—radioactivity of the solar system; the aurora, and the stars.

CROSS FIRE. In applying the rays of radioactive substances to deep seated growths, particularly where the rays must first pass through a layer of sound tissue, *Wickham* used the scheme of raying the growth from a number of different points, care being taken to have the bundles of rays strike the growth. Where possible, several applicators were applied, opposite each other or inclined at an angle, so that their rays crossed in the growth. In this way the sound tissue about the growth was protected from a harmful dose and the growth was sufficiently rayed to cause it to retrogress.

CURIE. The amount of radium emanation in equilibrium with 1 g. of radium (element). The curie at normal temperature and pressure has a volume of 0.585 cubic millimeters. Its weight is 0.006 milligrams.

RADIOACTIVE DECAY. The loss of a radioactive substance with time. The activity decays according to a simple exponential law, (Cf. Radioactive constant) being proportional at any instant to the number of atoms which remain unchanged at that time.

DELTA RAYS. Slow speed ($3x10^8$ cms. per sec.) electrons of secondary nature that appear when alpha particles impinge upon matter, whether solid, liquid, or gaseous. They are relatively greater in number than the alpha particles producing them. Polonium, which gives no beta rays, offers the best source of these rays. Under the influence of the magnetic field they describe small orbits and are returned to the active plate.

DEPOSITS. See Active Deposit.

DISINTEGRATION. See Transformation.

ELECTROSCOPES. A system consisting of two thin strips of gold or aluminum foil suspended from a vertical rod that is insulated from the surrounding protecting vessel. Upon charging, the leaves diverge, and the rate of discharge is a measure of the ioniz-

ation in the electroscope. In place of two leaves a stationary metal plate and one leaf may be used. When the gold leaves are replaced by two silvered quartz threads, which are held at the bottom by a bow of quartz we have the *quartz fibre electroscope.* By suspending a single quartz fiber, (silvered) centrally between two plates which are maintained at a potential difference of about 200 volts we have another form of electroscope known as the *string* electroscope. Any charge communicated to the fiber causes it to move. This instrument responds rapidly to the effect of a *single alpha particle* so that *Geiger* and *Rutherford* succeeded in recording the throws of the fiber when 1000 alpha particles entered the electroscope per minute. See R. p. 664-5.

An electroscope into which the active substance is introduced directly, or which is provided with a separate ionization chamber for the active substance is called an *alpha ray* electroscope. An instrument with an opening in the base covered with a sufficient thickness of foil to stop the alpha rays is called a *beta ray* electroscope. When the walls of the electroscope are made of lead 3 mm. thick we have a *gamma ray* instrument. When an electroscope is supplied with a scale, it may be calibrated and used to measure ionization currents quantitatively. It is then spoke of as an *electrometer.*

ELECTRON OR CORPUSCLE. The unit negative charge. When free moving it constitutes the beta rays or the cathode particle. Its charge is generally taken as 4.65×10^{-10} electrostatic units (E. S. U.). Its mass is 1/1700 that of the hydrogen atom, and its velocity is comparable to that of light. Its mass increases as its velocity approaches that of light.

EMANATION. The *active gaseous* disintegration products of the radioactive elements. See curie, active deposit, and radioelements. Three emanations are known:—radium, thorium, and actinium.

EMANATORIUM. A room in which patients may sit and inhale air containing radium emanation: An instrument used to furnish emanation for inhalation treatment.

EQUILIBRIA: SECULAR AND TRANSIENT. See Transformation. When the primary source (uranium or radium for example) of a series of transformation products changes so slowly that it remains nearly constant in amount over the period required for the products to attain approximate equilibrium the term *secular* equilibrium is applied. When the primary source, e. g., radium emanation, decays rather rapidly forming shorter lived products, then, after a time when equilibrium is established, the amounts of the different products are changing comparatively rapidly depending upon the quantity of parent present. The term *transient* is applied to such equilibrium. Equilibrium may be defined as the state existing when the number of atoms of a radioactive substance produced by the decay of its parent substance equals the number of atoms of the radioactive substance which decay in the same interval of time. A greater concentration than the equilibrium concentration of a radioactive element will not occur nor-

mally because the decay constants of the radio-elements are constants. Thus in a ton of uranium (metal) in equilibrium with radium there will be about 333 milligrams of radium (element) and in equilibrium with this radium there is about 0.002 milligrams of radium emanation. In a uranium mineral which is in equilibrium there is produced a radium atom for each uranium atom that transmutes, and in the same time one radium atom disintegrates giving rise to one atom of radium emanation, and likewise at the same time one atom of emanation decays. Under these conditions it is clear that the concentrations of radium and emanation, etc., with respect to the uranium are practically constant. The uranium is disintegrating so very slowly (half decay period 5,000,000,000 years) that its concentration will not vary appreciably in any ordinary period of time and so the equilibrium in an old uranium mineral is an example of secular equilibrium. The equilibrium between radium and radium emanation plus radium A, B and C is nearly attained in 30 days. Since in this time the radium has not sensibly diminished in quantity this again is an example of secular equilibrium. The equilibrium between radium emanation and radium A, B and C is attained in about seven hours. However, in seven hours the quantity of emanation has diminished to about 95 per cent of the original amount and since nothing like a state of constant activity is attained in such a case, this is an example of transient equilibrium.

EXCITED ACTIVITY. Same as active deposit.

FILTERS. The view that many are now inclined to accept as regards the action of the rays of radium (C. F. Lazarus, Berl. klin. Wochensch. 51, p. 201 and 208) is that it is not the gamma rays which act directly in causing changes in the cells, but rather the secondary rays (similar to beta rays) which are set up in the tissues by the gamma rays. The amounts of energy carried by three forms of rays from a gram of radium in equilibrium with emanation, Radium A, B, and C, are as follows (expressed in calories of heat, per hour): alpha rays 123, beta rays 4.3, and gamma rays 6.5. From this it is evident that the beta and gamma rays carry about the same total amounts of energy. However, the penetration is a factor of great importance in the therapeutical application of the rays and since the beta rays are far more readily absorbed than the gamma rays, it follows that an exposure to an unscreened radium tube will result in the absorption in the superficial layers of tissue of practically all the beta rays, (effect will extend several mm. in depth) whereas, the gamma rays can penetrate and produce effects at greater depths (ca. 3 to 5 cm.). This is the physical basis for the practice of using short exposures of unscreened or thinly screened applicators in the treatment of superficial growths, since here the primary beta rays have a sufficient effect, and the gamma ray effect is negligible. However, in the case of deep seated growths the penetrating qualities of the gamma rays must be utilized and in order to avoid a necrosis due to the action of the primary beta rays, these must be absorbed in suitable metal filters. Having absorbed practically all the beta rays, the gamma rays may act on a given tissue far longer, since

while *in toto* the gamma rays carry about the same amount of energy as do the beta rays, due to their penetrating power, there is not as much absorption per unit volume, as of the beta rays, and thus far longer exposures may be made before the same amount of energy has been applied to a given tissue. The time interval must be increased 100 to 200 fold to attain the same results with the gamma rays of radium in the first mm. of tissue, as would be given by the beta rays from the same amount of radium.

According to Rutherford two millimeters thickness of lead is sufficient to absorb nearly all the beta rays of radium. The absorbing power of metals for the beta and gamma rays may roughly be set as proportional to their densities, so that if 2 mm. of lead are sufficient to absorb all the beta rays of radium, it will require a thickness of about 8 mm. of aluminum or 3 mm. of brass to accomplish the same thing. The following table taken from Rutherford (p. 264) gives in the first column the various metals, in the second their densities, and in the third the number which is called their absorption coefficient for gamma rays:

Substance	Density	Absorption coefficient.
Mercury	13.6	0.642
Lead	11.4	0.495
Copper	8.81	0.351
Brass	8.35	0.325
Iron	7.62	0.304
Aluminum	2.52	0.111
Glass	2.52	0.105

When gamma rays emerge from a metal surface there are set up emergent secondary beta rays. These are called "rayons de Sagnac" by the French. In considering the choice of a material for use as a filter the following points must usually be considered, convenience (i. e. cost and durability); thickness required to give adequate screening (denser metals, thinner screen), penetrating quality of the emergent secondary beta rays and the quantity of this beta radiation. Allen and Eve have shown that the penetrating qualities of the secondary beta radiations about equals that of the primary beta rays. However, the absolute quantity of energy carried by the secondary rays is far less than the total energy of the primary beta rays and so the secondary rays can be screened off sufficiently by causing them to pass through several millimeters of paper, cloth or rubber (metal free) and the secondary beta rays set up by the gamma rays on emerging from these materials are negligible. If we set the quantity of emergent secondary beta radiation from lead as 100, then the quantities from the other metals are about as follows: Platinum, 95; brass, 70; iron, 68; copper, 67; aluminum, 75. From this standpoint it is true that brass, or copper makes a better filter material; however, the thickness must be about half again greater than that of a lead screen which would absorb an equal amount of beta rays. From this also aluminum would be less desirable, for while it would need to be used in greater thickness than even brass, to give the same screening effect, the total quantity of emergent secondary beta rays is greater than from copper or brass. As regards plat-

inum and gold they have a high specific gravity (ca. 20) and to attain the same screening as with lead, would only be used in about half the thickness, i. e., 1 to 1.5 mm. would do what 2 to 3 mm. of lead do.

GAMMA RAYS. A type of radiation analogous to X rays. They are extremely penetrating and non-deviable by magnetic or electric fields. Like the X rays the gamma rays are supposed to be ether vibrations of very short wave length.

HELIUM. See Alpha Rays and Transformation.

INDUCTION AND INDUCED ACTIVITY. Older terms for Active Deposits.

IONS. Cf. Conductivity of Gases. The energy required to produce a pair of ions is given as 5.5×10^{-11} ergs. The recombination of ions follows the law of mass action, and since ions occur in pairs the rate is proportional to the square of the concentration, provided the gas is free from dust particles. Under certain conditions ions form nuclei for the condensation of water, and this property has enabled C. T. R. *Wilson* to photograph the trail of ions made along the track of an alpha particle in air supersaturated with water vapor. Cf. R., pp. 46-9; 663-5. The number of ions produced by an alpha particle increases rapidly toward the end of its path, e. g., the alpha particle from Ra C products 2250 ions per mm. of path through the first cm. of its range, reaching a maximum of 7600 ions after traversing 6.5 cm. of air at atmospheric pressure and 12°C.

IONIZATION. The ionization produced in a gas by the complete absorption of the radiation is called the *total* ionization. *Natural* ionization is the ionization produced by the radioactive products in the air of an electroscope and the deposits on the walls. The normal number of ions in air ranges from 1000 to 2000 per cc.

IONIZATION CURRENT. The current produced between two charged plates by the ions present in the gas between the plates. When the electric field is sufficiently intense to prevent recombination of the ions produced by a radioactive agent the ionization current attains a maximum value called the *saturation current.*

IONIZATION CURVES. Curves obtained by plotting values of ionization current or its logarithm against some other function, such as volts, distance from source of radiation, range, thickness of absorbing layer, etc. When ionization values are plotted against time the resulting curves represent recovery or decay of the active product.

IONIZATION CHAMBER. The electrode system and containing vessel used in measuring ionization currents produced by radioactive substances.

IONIUM. A member of the U-Ra series of radioactive elements. Parent, UX., or UII; Disintegration product, radium; At. Wt., 230.5; half period, at least 100,000 yrs.; range of alpha particle, 3 cm. Inseparable from thorium, its nearest chemical analog.

LIFE: AVERAGE PERIOD. The period of average life is the sum of the separate periods of future existence of all the individual atoms divided by the number in existence at the starting point.

The average life is expressed by $1/\lambda$, where λ is the radioactive constant of the substance.

LEAD, RADIOACTIVE. See Radio-lead, Radium D, and Polonium. The activity of lead separated from uranium minerals is due to traces of Ra D, Ra E, and Po.

MAGNETIC SPECTRUM. See Spectrum.

MESO-THORIUM. Ms I: the direct product of Th: rayless; half period, 5.5 yrs.; chemical analog of Ra and nonseparable from it. Ms II, the product of Ms I; half period, 6.2 hrs. emits beta and gamma rays. See Table III. Commercially mesothorium is spoken of in terms of "milligrams." Actually weight for weight, pure mesothorium (which has never been prepared) would be about 350 times more active than radium, since it is disintegrating about 350 times faster than radium. What is called "one milligram" of mesothorium, commercially, is that quantity of mesothorium that has a gamma ray effect equal to the gamma ray effect of one milligram of *pure radium bromide* (0.536 milligram radium element).

MILLIGRAM. One thousandth of a gram.

MICROGRAM. One millionth of a gram.

MILLICURIE. One thousandth of a curie, q. v.

MICROCURIE. One millionth of a curie, q. v.

MILLIGRAM HOURS. Frequent use is made of the term milligram-hours referring to the therapeutic application of radium and mesothorium. One milligram of radium bromide applied for ten hours is 10 milligram-hours, or ten milligrams applied for one hour is 10 milligram-hours. This is a very poor way of stating results, since the concentration factor is wholly ignored. If the number of milligrams of pure radium salt and kind of applicator are specified and the time of application, there is no doubt as to what procedure was used; and unless such data is given, results are much less useful for purposes of comparison.

NITON. A name proposed by *Ramsay* for radium emanation, q. v.

NORMAL AIR LEAK. See Air Leak.

PENETRATING POWER. Cf. Absorption. A thickness of 0.005 mm. of aluminum stops one-half the alpha rays; 0.5 mm., one-half the beta rays; and about 80 mm. of aluminum cut down the gamma radiation one-half.

PERIOD OF HALF LIFE. (Often called the "period" of a radio element.) That interval in which half of any given quantity of a single sort of radio active atoms disintegrates is called the period of half life. Since the rate of transmutation of a given radio element is a constant (cf. radioactive constant) the time required for half of any quantity of a given element to transmute is independent of the quantity. So for example if there is a curie of emanation in one vessel and a millicurie in another, after 3.85 days there will remain 0.5 curie in the first vessel and 0.5 millicurie in the second vessel. 3.85 days after that there will be 0.25 curie and 0.25 millicuries respectively in the two vessels. 3.85 days is the period of half life, or briefly, the period of radium emanation. After an interval equal to ten times the period for any given

element, it may be shown by calculation that only about 0.1% remains unchanged. Thus (see radium emanation) after 40 days there is left only 0.07% of any quantity of emanation. The period of radium is about 2,000 years, so that after 20,000 years practically all of a given quantity of radium will have disintegrated. The period of mesothorium I is 5.5 years, and in about 55 years practically all of any quantity of mesothorium I will have decayed. On the other hand, when the period of the parent element is long in comparison with the period of the decay product as in the case of radium and radium emanation, or thorium and mesothorium I, the rate of accumulation of the decay product (setting the equilibrium quantity (q. v.) of the decay product as unity) may be estimated from its period. For example in a sealed radium preparation initially free from emanation, there accumulates in 3.85 days one-half the equilibrium quantity of emanation. In another 3.85 days there is 75% of the equilibrium amount of emanation and in 10 x 3.85 days there is 0.999 of the equilibrium amount of emanation.

PHOSPHORESCENCE OF RADIO-ELEMENTS. Compounds of radium emit light. This "self luminosity" of radium salts and other radioactive substances is called radioactive phosphorescence. When zinc blend, barium platino-cyanide, diamond, and some other substances are exposed to the radiations from radioactive substances they become phosphorescent as when exposed to X rays. See, Scintillations.

PHOTOGRAPHIC ACTION OF RAYS. Alpha, beta, and gamma rays all affect a photographic plate. Alpha rays affect it only within their range, and since they are stopped completely by thin sheets of paper, the photographic action of radioactive bodies is mainly due to the beta rays. *Since some non-radioactive bodies also affect the photographic plate the photographic method of detecting radioactivity is not a rigorous test.*

PITCHBLENDE. Minerological name, Uraninite. Its principal constituent is uranium oxide, U_3O_8. Its composition is complex: lead, thorium, helium and oxides of the rare earths always occur in it. The uranium content of pitchblende generally ranges between 50 to 80%. The radium content of pitchblende is 3.33×10^{-7} gm. per gm. of uranium. Mme. *Curie* first isolated radium from the residues of pitchblende.

POLONIUM. (Radium F or Radio-tellurium). The last active member of the radium series; parent, Ra E; Probable disintegration product, lead; At. Wt. 210; half period, 136 days; emits alpha rays only of range 3.77 cm. Precipitated from solutions by hydrogen sulphide, on a bismuth or copper plate, or by electrolysis.

RADIATIONS, Cf. *Becquerel* rays; Primary, secondary, characteristic, q. v., penetrating, recoil, (see, recoil atom). Alpha, beta, and gamma rays constitute the *primary* radiations, the last named being the penetrating radiation. These radiations are characteristic of the different types of radioactive forms of matter. Secondary rays result when certain types of primary rays impinge

upon matter, thus delta rays are produced as a secondary radiation by alpha rays.

RADIO-CHEMISTRY. That branch of chemistry dealing with the chemical properties of the radio-elements. Reference book: *Soddy* —"The Chemistry of the Radio-Elements."

RADIO-ELEMENTS. The collective name for the elements possessing radio-activity, whose fundamental characteristic is the spontaneous emission of primary radiations, q. v., accompanied by the simultaneous appearance of new types of matter.

RADIUM. The prominent member of the uranium radium series of radioactive elements, belonging to the alkaline earth group of elements. Its parent is ionium and its disintegration product radium emanation. The U-Ra series follows: (See table). P equals half period; L equals average life.

TABLE II—Uranium-Radium Series

Name	At.Wt.	P	L	Radioactive Constant	Rays
Uranium I	238.5	$5x10^9$ yrs.	$7.2x10^9$ yrs.	$1.4x10^{-10}$ yrs.	alpha
Uranium X	234.5	34.6 days	35.5 days	0.028 days	beta, gamma
Uranium II	236.5	10^6 yrs.?			alpha
Ionium	230.5	$2x10^5$ yrs.?			alpha
Radium	226	2000 yrs.	2880 yrs.	0.000346 yr.	alpha
Emanation	222	3.85 days	5.55 days	0.0075 hr.	alpha
Ra A	218	3.0 min.	4.32 min.	0.231 min.	alpha
Ra B	214	26.8 min.	38.7 min.	0.0258 min.	beta, gamma
Ra C	214	19.5 min.	28.1 min.	0.0355 min.	alpha, beta, gamma
*Ra C^1	210?	1.4 min.	2.0 min.	0.495 min.	beta
Ra D	210	16.5 yrs.	23.8 yrs.	0.042 yrs.	beta
Ra E	210	5.0 days	7.2 days	0.139 da.	beta, gamma
Ra F (Po).....	210	136 days	196 days	0.0051 da.	alpha

*Ra C^1 is considered a branch product.

RADIUM SALTS. (Cf. activity). The word "radium" as it has come into use has signified a radium salt—and in a stricter sense, pure crystalline radium bromide ($Ra\ Br_2\ 2H_2O$). However, quite a number of the salts of radium are now used and in describing preparations it is most accurate to state the radium element content of the salt. This makes comparisons between the different salts a simple matter, since in most cases the purity of the salt is of less consequence than its radium element content. The salts most commonly used are the bromide, chloride, sulfate and carbonate. These salts as used in the local application of the rays are generally not pure radium salt but a mixture of radium and the corresponding barium salt. Preparations containing 40 to 60% of pure radium salt form the greater part of the world's radium output. The hydrous bromide ($Ra\ Br_2\ 2H_2O$), when pure, contains 53.6% of radium element. The pure anhydrous radium bromide ($Ra\ Br_2$) contains 58.6% of radium element. Pure radium sulfate ($Ra\ SO_4$) contains 70.2% radium element. Pure radium chloride ($Ra\ Cl_2$) contains 76.1% radium element and pure radium carbonate ($Ra\ CO_3$) contains 79.0% of radium element. The chloride and bromide are soluble in water while the sulfate and carbonate are insoluble. The carbonate is soluble in dilute

acids, whereas the sulfate is insoluble. One milligram of radium element is contained in 1.87 mgm. of pure hydrated bromide, in 1.42 mgm. of pure sulfate, in 1.31 mgm. of pure chloride and in 1.265 mgm. of carbonate. The radium salts of commerce are white or greyish powders which glow more or less brightly in the dark.

RADIUM EMANATION. The gaseous radioactive product in the uranium-radium series. Its density is 111.2 (hydrogen equals 1); a noble gas, whose nearest analog is xenon. The gas is easily separated from radium solutions by boiling. Cf. *"Curie."* The identity of the alpha article, after loss of charge, with the helium atom, was first shown by *Ramsay* and *Soddy* in the production of helium in spectroscopic quantity from radium emanation. The disintegration products of the emanation constitute the active deposit of radium, q. v. Its solubility coefficient in water at 20° is 0.30. The Boltwood standard of radioactivity is based upon the quantitative determination of radium emanation by electroscopic methods, and the fact that radium and uranium occur in minerals in radioactive equilibrium.

TABLE OF DECAY AND GROWTH OF RADIUM EMANATION.

A = fraction of emanation remaining after time t.

B = fraction of equilibrium amount of emanation formed in t days in a radium preparation initially free from emanation.

Time	A	B	Time	A	B
0	1.000	.0000	8 days	.2369	.7631
1 hr.	.9925	.0075	9 days	.1979	.8021
2 hrs.	.9851	.0149	10 days	.1653	.8347
3 hrs.	.9777	.0223	11 days	.1381	.8619
4 hrs.	.9704	.0296	12 days	.1153	.8847
5 hrs.	.9632	.0368	13 days	.0963	.9037
6 hrs.	.9560	.0440	14 days	.0805	.9195
7 hrs.	.9489	.0511	15 days	.0672	.9328
8 hrs.	.9418	.0582	16 days	.0561	.9439
9 hrs.	.9347	.0653	17 days	.0469	.9531
10 hrs.	.9277	.0723	18 days	.0392	.9608
11 hrs.	.9208	.0792	19 days	.0327	.9673
12 hrs.	.9139	.0861	20 days	.0273	.9727
13 hrs.	.9071	.0929	21 days	.0228	.9772
14 hrs.	.9003	.0997	22 days	.0191	.9809
15 hrs.	.8936	.1064	23 days	.0159	.9841
16 hrs.	.8869	.1131	24 days	.0133	.9867
17 hrs.	.8803	.1197	25 days	.0111	.9889
18 hrs.	.8737	.1263	26 days	(2)928	.9907
19 hrs.	.8672	.1328	27 days	(2)775	.9923
20 hrs.	.8607	.1393	28 days	(2)647	.9935
21 hrs.	.8543	.1457	29 days	(2)541	.9946
22 hrs.	.8479	.1521	30 days	(2)452	.9955
23 hrs.	.8416	.1584	40 days	(3)747	.9993
1 day	.8353	.1647	50 days	(3)123	.9999
2 days	.6977	.3023	60 days	(4)204	....
3 days	.5827	.4173	70 days	(5)337	....
4 days	.4868	.5132	80 days	(6)558	....
5 days	.4066	.5934	90 days	(7)922	....
6 days	.3396	.6604	100 days	(7)152	....
7 days	.2837	.7163			

The numbers in brackets, e. g., (6) refer to the number of O's before the first significant figure. From *Rutherford's* "Radioactive Substances and Their Radiations," page 665.

RANGE. The range of alpha particles is the distance in air at 760 mm. and 15° C over which the alpha particle will produce ions.

RECOIL ATOMS. When an alpha particle is shot off from an atom with high velocity the remainder of the atom recoils with a velocity inversely proportional to its mass. The larger atom which thus recoils is called the "recoil atom," or "rest-atom."

RECOMBINATION OF IONS. See Ions.

ROENTGEN RAYS, OR X RAYS. Radiations set up when a cathode ray beam is suddenly stopped by striking a solid object. The rays are highly penetrating, affect a photographic plate, and are very similar to gamma rays q. v. They have the power of ionizing air but this ionization is due to secondary beta rays set up by the X rays.

SAGNAC RAYS. Same as secondary rays, see under Filters.

SECONDARY RAYS. See under Filters.

SATURATION CURRENT. See, Ionization Current.

SCINTILLATIONS. The phosphorescence produced by alpha rays upon a screen of zinc sulfid when examined through a low power microscope is seen to consist of numerous instantaneous flashes of light called scintillations. When two alpha particles are emitted almost simultaneously, as is the case when a very short-lived alpha ray product occurs in a series, the flashes appear on the screen in pairs, and are termed double scintillations.

SCINTILLASCOPE OR SPINTHARISCOPE. An instrument devised by *Crookes* for making visible the scintillations from a speck of rarium. Cf. Scintillations.

Sidot's BLEND. A special form of zinc sulfid is known as *Sidot's* hexagonal blend.

SPECTRUM, MAGNETIC. The beta radiation from the radio-elements is generally not homogeneous, and may be separated by the magnetic field into several sets of rays. Thus, radium B emits several groups whose velocities in terms of light are respectively, .36, .41, .63, .70, .74.

STANDARDS. The international radium standard is a specimen of pure radium chloride prepared by Mme. *Curie* and kept at the International Bureau of Weights and Measures at Sevres near Paris. A secondary is kept in Vienna. The great confusion consequent to the discrepancies which were found to exist between the so-called radium standards of the various workers in radioactivity, led the Congress of Radiology and Electricity, which met in Brussels in 1910, to appoint a committee to make arrangements for the preparation of the International Radium Standard. 21.99 milligrams of pure anhydrous radium chloride prepared by Mme. *Curie*, were sealed in a glass tube, and this preparation, containing 16.75 milligrams of radium element, was accepted by the Committee as the International Radium Standard. Preparations of pure radium chloride, purified by *Honigschmidt* at the Radium Institute of the Vienna Academy of Sciences, for atomic weight work, were compared by the Committee with Mme. *Curie's* preparations and found to agree within a limit of 1 part in three hundred.

These three Vienna preparations contained 10.11, 31.17 and 40.43 milligrams of anhydrous radium chloride.

Due to its high activity, it is not convenient to work with even a hundredth part of a milligram of pure radium salt in an ordinary electroscope, and quantities of radium of from 0.01 milligram up to a gram are best compared by means of the gamma rays. When a radium salt has been kept sealed for a month, the maximum amount of emanation and active deposit has accumulated and the gamma ray activity reaches a maximum. Under these conditions, it is possible to determine the quality of radium in a preparation using an electroscope which must have a case made of lead, at least a centimeter thick [to absorb beta rays]. The radium preparation is placed near the charged electroscope and the rate of discharge is observed. This discharge is due to the gamma rays, which pass through the lead case and ionize the air inside of the electroscope. The preparation is removed to a great distance, or put in a thick lead box and a standardized preparation [i. e. one which contains a known amount of radium] is placed in the *same position,* near the electroscope and its gamma ray ionization current observed. The rates of discharge of the instrument are proportional to the quantities of radium contained in the preparations, so that the unknown quantity of radium can easily be calculated. Other standards that have been used are: (1) *Boltwood* Standard, the emanation in equilibrium with a known weight of pure radium salt, or uranium mineral of known radium or uranium content; (2) *McCoy* Standard, the total amount of activity from 1 gram of uranium element as oxide in the form of a film of maximum constant activity; (3) *Mache* unit (m. u.) is a term to express *concentration* of radium emanation. It is defined as the saturation ionization current due to the radium emanation (free from decay products) from a liter of solution or gas, expressed in electrostatic units multiplied by 1000. One microcurie is equal to 2700 mache units.

THORIANITE. A rare mineral from Ceylon composed of 60 to 70% of ThO_2 and 10 to 30% of U_3O_8.

THORIUM. The first member of the thorium series of radium-elements given in Table III.

TABLE III—Thorium Series.

Name	At.Wt.	P	L	Radioactive Constant	Rays
Thorium	232	1.3×10^{10} yrs.	1.9×10^{10} yrs.	5.3×10^{-11} yrs.	alpha
Meso Th. I.....	228	5.5 yrs.	7.9 yrs.	.126.yr.	rayless
Meso Th. II.....	228	6.2 hrs.	8.95 hrs.	.112 hr.	beta, gamma
Radio Th.	228	2.0 yrs.	2.88 yrs.	.347 yr.	alpha
Th. X	224	3.65 days	5.27 days	.190 da.	alpha
Th. Em.	220	54 sec.	78 sec.	.0128 sec.	alpha
Th. A.	216	.14 sec.	0.20 sec	4.95 sec.	alpha
Th. B. 212		10.6 hrs.	15.3 hrs.	.0654 hr.	weak beta
Th. C.	212	60 min.	84.6 min.	.0118 min.	alpha, beta, gamma
Th. C^1 *.....	212	Very short			alpha
Th. D.	208	3.1 min.	4.47 min.	.224 min.	beta, gamma

*Th C^1 is regarded a branch member.

TRANSFORMATION. The theory of successive transformation or atomic disintegration of *Rutherford* and *Soddy* assumes that the atom of the radio-elements, at some time in its life history suddenly

disrupts and generally ejects a charged particle with high velocity, leaving new atom possessing very different chemical properties. The alpha particles emitted in this process are positively charged holium atoms, and the rest atom is a new element with an atomic mass of four units smaller. This fundamental process in the radio-elements follows a simple exponential law:—

$$N/No = e^{-\lambda t}$$

derived from the law of mass action, that the rate of change at any time is directly proportional to the quantity present. N_0 is the number of atoms present initially, N , the number present at the time t, and λ, a constant characteristic of the species of atoms, and known as the radioactive constant, q. v. When equilibrium is attained, the number of atoms of each product decaying is compensated by the number produced, the amounts of each product being inversely proportioned to its radioactive constant. Unlike the constant of monomolecular chemical changes, its value is independent of the temperature, chemical constitution, and any other factors that influence the speed of chemical changes.

URANIUM. The first member of the uranium-radium series, q. v. Its principal sources are pitchblend and carnotite. A member of the iron group. For its estimation and separation see *Brearley*, "The Analytical Chemistry of Uranium."

URANIUM X. The product responsible for the photographic action of uranium compounds, and first separated from uranium by chemical methods by *Crookes*. See U-Ra series.

URANINITE. Pitchblend.

VARNISH APPLICATORS. For applying radium and mesothorium to superficial growths or over extensive growths, the radioactive substance in the form of a sulfate salt is embedded in a hard resistent varnish on a suitable metal plate. Varnish applicators are usually square or circular in shape and the amount of radium (element) per square centimeter determines their "strength." In accordance with the practice of the London Radium Institute, a "full strength" applicator contains 5.36 milligrams of radium element per sq. cm. of area. "Half strength" and "quarter strength" applicators contain respectively 2.68 and 1.34 milligrams of radium element per sq. cm. of varnish surface. It follows therefore that the total quantity of radium in a varnish applicator will depend on its area and its "strength." Because of the rapid deteriorations of the varnish under the action of the rays, half and quarter strength are preferable, since they may be used for years before revarnishing is necessary. Cf. British Med. Jour., Jan. 25th, 1913, page 164.

VELOCITY. The velocity of the alpha rays varies between 5 and 7.5% that of light. The velocity of the alpha particle from Ra C is 2.06×10^9 cm. per sec. The range of the particle depends upon the velocity. The initial velocity of beta particles varies and in some cases approaches that of light, e. g., the velocity of the beta rays from radium C ranges from 0.78 to 0.957 that of light. See Spectrum. The gamma rays have the velocity of light.

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